Article

Controversies, development and trends of biofuel industry in the world

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Abstract
Controversies, development and trends of biofuel industry in the world were discussed in present article. First-generation biofuels, i.e., grain and land based biofuels, occupied large areas of arable lands and severely constrained food supplies, are widely disputed. They have been replaced by second-generation biofuels. The raw materials of the second-generation biofuels include plants, straw, grass and other crops and forest residues. However, the cost for production of the second-generation biofuels is higher. Therefore the development of the third-generation biofuels is undergoing. The third-generation technologies use, mainly algae, as raw material to produce bioethanol, biobutanol, biodiesel and hydrogen, and use discarded fruits to produce dimethylfuran, etc. Different countries and regions are experiencing different stages of biofuel industry. In the future the raw materials for biofuel production will be focused on various by-products, wastes, and organisms that have not direct economic benefit for human. Production technologies should be improved or invented to reduce carbon emission and environmental pollution during biofuel production and to reduce production cost.

Keywords biofuel; industry; trends; controversies; world.

1 Introduction

The development of human society depends on the development of production capacity, and the sustainable development of production capacity must be supported by a steady supply of energy. At present the energy shortage, energy exhaustion, or energy crisis becomes a huge challenge for the development of human society. Fossil fuels (coal, petroleum, natural gas, etc.) account for 80% of the consumption of basic energy in the world, of which about 57% is for transportation (IEA, 2006). Fossil fuels are nonrenewable resources and the exhaustion of global fossil fuels is unavoidable. Based on a report (BP, 2006), global oil reserves will be exhausted in the about 30 years. Natural gas and coal will be exhausted in about 60 years and 160 years, respectively. Furthermore, human consumption of fossil fuels has led to a series of problems, such as global warming, acid rain, desertification, water pollution, biodiversity loss, and other serious ecological and environmental problems (Zhang and Liu, 2012; Zhang and Wu, 2012).

Biofuels refer to the fuels manufactured from the organisms and their metabolic excreta that originate from all products or by-products of agriculture and forestry, industrial waste and garbage (Herrera, 2006; Morton, 2006; Pearce, 2006; Evangelos et al., 2009; Sayadi et al., 2011). In most cases, biofuels refer to the liquid biofuels such as bioethanol, methanol, and biodiesel. Liquid biofuel products are considered to be the best alternatives or supplements for gasoline and petrochemical products. Like wind energy and solar energy, biofuels are renewable energy. There are huge reserves of raw materials for biofuel production on the earth. The biofuel energy stored in the plants each year on the earth is equivalent to 20 times of the annual consumption of fossil fuels. Most of the raw materials of biofuels are plants and their metabolic excreta. Plants absorb carbon dioxide in the atmosphere and biofuels are burned to emit the same amount of carbon dioxide into the atmosphere. The process is quick and thus biofuels will not increase the total stock of carbon dioxide in the atmosphere. Biofuels are thus called carbon-neutral fuels (Morton, 2006).

Biofuel industry is developing quickly in the world. However, because there are various biofuels that have different development patterns, biofuel industry have experienced some challenges. In this paper, we will discuss development, challenges and trend of biofuel industry in the world.

2 Raw Materials of Biofuels

Biofuels are manufactured from biomass resources. Biomass refers to all living and dead biological substances and metabolites. Biomass resources include all animals and plants and their excreta, waste of agriculture and forestry, scraps of food processing and forest-products processing, processed garbage of food and beverage industry, municipal solid waste, sewage, black liquor, etc (IEA, 2007; CNEN, 2007). All energy of biomass is originally from the photosynthesis of autotrophs which absorb and store solar energy in organisms.

Fig. 1 shows unexploited biomass of the world in 1998.

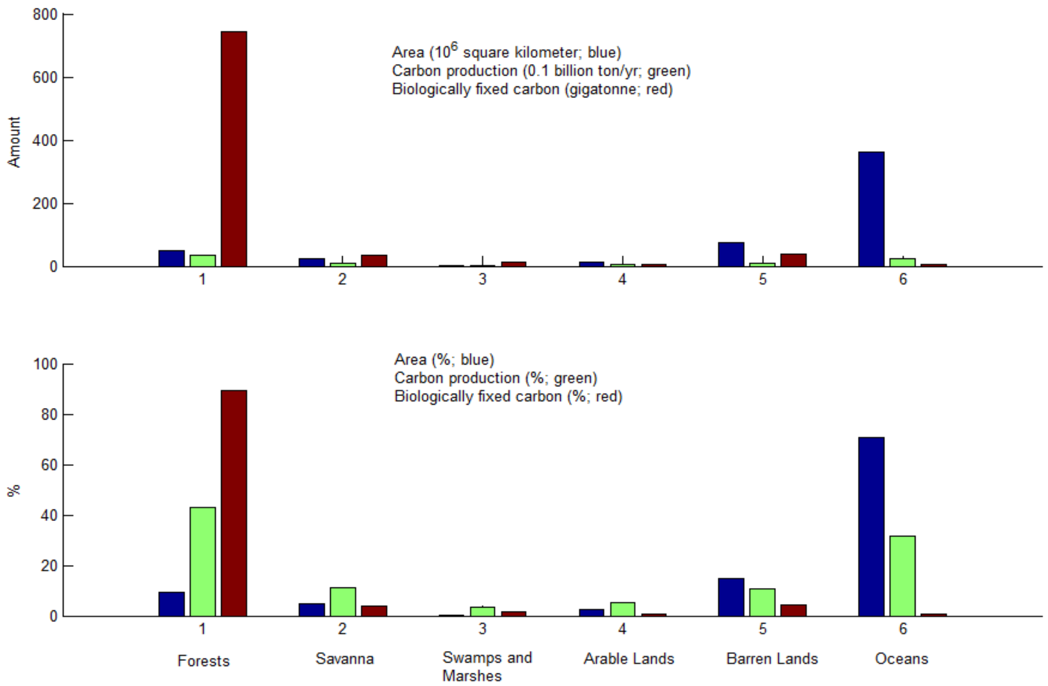

Fig. 1 Undeveloped potential biomass in 1998 (Klass, 1998).

Based on the data in 1998, it can be found that arable lands accounted for 2.7% of production area of the global biomass and produced 4.1 Gt of carbon annually, while the biologically-fixed carbon reached 6.3 Gt. Forests fixed 744 Gt of carbon which accounted for nearly 90% of total biologically-fixed carbon on the earth. However, deforestation is usually used to increase arable lands and grazing lands (Zhang et al., 2006), and forests are thus reducing.

Other sources of biomass are mainly various residues. Such as municipal solid waste, sewage, industrial waste, animal dung, crop and forest residues, etc. Taking an example, forest residues and agricultural wastes accounted for more than 70% in the United States, but only less than 30% of them were utilized. In the United States, the potential biomass energy reached 15.8 EJ/yr but only 1.1 EJ/yr was utilized (Klass, 1998). The fact demonstrates that various biological residues have great potentiality for biofuel production.

3 Types of Biofuels

Biofuels can be divided into solid biofuels, liquid biofuels and gaseous biofuels.

3.1 Solid biofuels

Historically solid biofuels are the most used biofuels. The primitive solid biofuels mainly include coal bricks, briquettes, olive cake, sawdust, firewood, wood, bark, straw bundles, etc (Alakangas et al., 2006). They also include municipal solid wastes, especially paper products and plastics. Solid biofuels are mainly used for industrial heating systems and power plants to generate electricity.

3.2 Liquid biofuels

Liquid biofuels include bioethanol, biodiesel, liquid hydrogen, methanol, biobuethanol, cellulosic ethanol and synthetic biofuels (Vertes et al., 2006). Bioethanol and biodiesel are currently the most common biofuel products.

3.2.1 Bioethanol

Biological materials rich in starch and sugar are directly fermented, distilled and purified, and bioethanol is thus obtained. The suitable raw materials include sugar cane, sugar beet, sorghum, corn, straw, cotton, corn stalks, etc. Different raw materials are used by different countries. Brazil, India and South Africa use sugar cane to manufacture bioethanol. The United States uses corn mainly, seconded by wheat. China uses corn, wheat, rice, cassava, and sweet potatoes. As a clean fuel, bioethanol can be used in combustion motor for transportation. It can also be used as a fuel for power generation, fuel cells, as well as the raw material in chemical industry.

3.2.2 Biodiesel

Biodiesel, also known as fatty acid methyl ester, is extracted from vegetable oils, recycled kitchen oils, or animal fats. They are long-chain fatty acid alkyl ester [13]. Biodiesel can be used in compression-ignition engines. It is usually used after blending with petroleum-based diesel. Biodiesel is mainly used in Europe, in particular Germany. In contrast, research, production and application of biodiesel in Asian and African countries are still in their infancy.

3.2.3 Gaseous biofuels

Gaseous biofuels, mainly methane, are the least used biofuels. Gaseous biofuels are gases generated by the gasification process of biomass. They are generated through industrial or microbial degradation of biomass. The gases generated in the process contain one or more of the following gases: methane (CH_4), hydrogen (H_2), carbon monoxide (CO) and carbon dioxide (CO_2). Wood, forest residues, agricultural wastes and fertilizers can be used as the raw materials to produce methane for living gas, industrial fuel, ammonia (NH_4) production and raw materials for chemical industry.

4 Controversies on Biofuel Industry

Overall, biofuels are renewable with respect to nonrenewable fossil fuels, which can reduce the emission of carbon dioxide. However, so far in a few cases its environmental performance is better than the corresponding fossil fuels. In addition, the total cost of the biofuel industry (production, supply, etc.) is still relatively high, such that it is less attractive. There are still various controversies on biofuel industry.

4.1 Controversies on ecological benefit of biofuel industry

The researchers of the University of Minnesota found that biodiesel would emit 41% lower greenhouse gas compared to ordinary fossil diesel. Bioethanol produced 12% lower greenhouse gas compared to gasoline. The combustion energy of the biofuel was greater than the total energy consumed in the cultivation and refining process of raw materials of biofuels. Among these biodiesel produced 93% higher energy than the energy producing biodiesel, and the energy of ethanol was 25% higher than the consumed energy (Wang and Guo, 2008).

However, the negative impacts of biofuels on the environment are also significant, which are mainly occurred in the production process of biofuels. Cultivation of corn, soybeans and sugar cane has caused a series of environmental problems. Bioethanol production in the United States, for example, heavily uses nitrogenous fertilizers, phosphorous fertilizers and pesticides. They have resulted in pollution of air, soil and water. Residual fertilizer used in the United States swept through the Gulf of Mexico and resulted in a dead zone lacking of oxygen, so that most of the ocean organisms can not survive there (Rabalais et al., 2002). Furthermore, the nitrogen oxides generated from nitrogenous fertilizers are also important greenhouse gases. In addition, biofuel industry is at a certain degree unfavorable to biodiversity, land protection and pest control, because farmers may choose to cultivate corn only to replace intercropping.

Development of biofuel industry conflicts with food production, forest protection, and other land use patterns. The most obvious example is the deforestation of tropical rain forest in the tropics, which not only threat biodiversity, but also eliminates carbon sinks. This change in land uses has established a “carbon debt” (Inderwildi and King, 2009).

In Brazil, several million hectares of virgin forests have been destroyed due to the large-scale cultivation of sugar cane for producing bioethanol. In Malaysia, palm trees are massively planted. Palm oil is used to produce mixed diesel fuel. Massive planting of palm trees destroyed large areas of tropical rainforests. About 400 years would be needed to repay the resultant carbon debt (Fargione et al., 2008).

In fact, a normal ecosystem will also produce biofuels with better ecological benefit. Tilman et al. (2006) studied the grassland vegetation and proposed a biofuel-producing pattern with low-input and high-output. In this experiment, the energy input-output ratio was 5.44: 8.09, which was two to five times higher than corn ethanol and soy diesel. And greenhouse gas emission reduced 6 to 10 tons per hectare on the average, while the emission reduction of corn ethanol and soy diesel was less than 1 ton (Shi and Li, 2009).

4.2 Controversies on economic benefit of biofuel industry

4.2.1 Competition for grains between human and vehicles

To develop biofuel industry, the United States and the European Union have put massive subsidies to facilitate the conversion of food crops into biofuels. However, global food demand is expected to increase in the future (Zhang et al., 2007). The global demand for transportation fuels, however, is expected to increase faster (EIA, 2008). Food crops can only meet a small portion of raw materials for biofuel production. According to a report, the sharp rising food price in 2008 was in large part (about 75%) caused by the biofuel production from food crops (Mitchell, 2008). Food security worldwide has been threat due to biofuel production from food crops.

The United States is one of the world largest corn producers. It produces about 300 million tons of corn each year, among which 55% is for forage, 25% is for industrial use (and ethanol accounted for about 70%), and 20% is for exports. In the two years of 2006 and 2007, the United States produced 16 million and 21 million tons of ethanol respectively. In fact, from 2004 to 2007 the corn exports of the United States have been increasing because farmers’ enthusiasm for corn production (Shi and Li, 2009). On the other hand, a report held that 25% of the rising price of grains had been resulted from the rising of oil price in 2007 (Shi and Li, 2009). The impact of energy price on food sales was 2-3 times of foods themselves.

The controversies about competition for grains between human and vehicles focus on corn bioethanol, especially in the United States. In fact, corn and bioethanol are only one of the raw materials and biofuels in the families of raw materials and biofuels, respectively. The simple negation to biofuels is not fully reasonable. Cellulosic ethanol is thus a promising biofuel.

4.2.2 Economic debate

Some people argued that biofuel industry should develop without governments' financial subsidies. Its development should follow general economic laws. However, opposition views held that these financial subsidies will reduce gradually as it gradually becomes a new growth point for economy. For example, in 2007 the United States subsided $ 3 billion to bioethanol, but reduced $ 6 billion of subsidy to agricultural products and $ 20 billion of trade deficit, in which $ 15 billion was for reducing oil import from other countries. In Brazil, bioethanol made from sugar cane does not need any subsidies and can compete with exported oil. The price of vehicle bioethanol in Sao Paulo was only 54% of gasoline (Shi and Li, 2009).

According to a survey of the European Commission, the biofuel production of European countries in 2007 reached 1% of vehicles' fuel consumption. It helped to protect or create 45000-75000 jobs (Demirbas, 2008).

A twenty years' study by Argonne National Laboratory, USA, showed that for each input fossil energy unit, the production capacity of electricity, gasoline, coal, corn ethanol and cellulosic ethanol were 0.45, 0.81, 0.98, 1.36, and 10.31, respectively. All fossil fuels had negative production capacity whereas biofuels had positive production capacity (Shi and Li, 2009). However, Pimental and Patzek (2005) pointed out that energy balance of corn ethanol production was negative (-29%) in view of all energy inputs needed. But other researchers have questioned their viewpoint.

In general, the economic benefit of biofuel industry depends on the types of biofuels, the technology, scale and efficiency for producing biofuels, etc. We are not able to draw a unique conclusion for all biofuels. Overall the production cost of biofuels in developed countries is generally higher than that in developing countries.

5 Trends of Biofuel Industry

In view of controversies on the first-generation biofuels, the EU introduced some policies on a new generation of biofuels in April 23, 2009. Clear targets for development of biofuel industry were proposed in two directives, i.e., "Renewable Energy Directive" (RED) and "Fuel Quality Directive" (FQD).

RED described the mandatory targets for biofuel industry, i.e., by 2020, each member country of EU should ensure that the use of renewable energy consumption of domestic traffic accounts for at least ten percent of the total transport energy consumption (Zen, 2010). RED provided a lot of legal and financial supports to encourage research, development, production and use of second-generation biofuels.

FQD requested that the amount of ethanol blended with gasoline should increase to 10%. At the same time, it introduced a new mechanism, decarburization mechanism. The mechanism requested that before December 31, 2020, fuel suppliers must cut 10% of emission of greenhouse gas in fuel life cycle (Zen, 2010).

5.1 Second-generation biofuels

First-generation biofuels, i.e., grain and land based biofuels, occupied large areas of arable lands and severely constrained food supplies, have been quickly replaced by second-generation biofuels. The raw materials of the second-generation biofuels include plants, straw, grass and other crops and forest residues. These cellulosic raw materials are pyrolysed to be converted into biofuels including bioethanol and biodiesel. The second-generation biofuels are expected to meet the 1/3 of world's energy needs (Zhang, 2009).

5.1.1 Second-generation bioethanol

The second-generation bioethanol includes two products, cellulosic ethanol and cellulosic bio-gasoline. The production technologies for cellulosic ethanol include sulfuric acid / enzyme hydrolysis - fermentation technology (Gerald, 2010a), sulfuric acid hydrolysis - fermentation technology, acid hydrolysis - fermentation

- esterification - hydrogenation technology (Gerald, 2008; Ladisch et al., 2010), and enzymatic hydrolysis - fermentation technology (Gerald, 2010a, c). Among these technologies, enzymatic hydrolysis can replace sulfuric acid hydrolysis and become the major technology to produce cellulosic ethanol. Low density of cellulosic ethanol leads it hard to blend with gasoline. So cellulosic bio-gasoline has been developed and produced. Major technologies for producing cellulosic bio-gasoline included fast pyrolysis - MHUG technology, and the Bio-Forming technology (Gerald, 2010b).

Trees contain both lignin and cellulose. To use cellulose as a raw material for biofuel production, we need to remove lignin from tree materials. Some insects, like Asian longhorned beetle (*Anoplophora glabripennis*), can break down lignin, and leave cellulose for biofuel production.

5.1.2 Second-generation biodiesel

Use edible and non-edible oils and fats of plants and animals as raw materials for the catalytic hydrogenation, and thus produce non-fatty acid methyl ester. The resultant biodiesel is called second-generation biodiesel (Yao and Wang, 2010). Compared with the first-generation biodiesel, the density of second-generation biodiesel is lower. It has a higher cetane number and can arbitrarily blend with petroleum diesel. Taking it as the fuel of the diesel vehicles, the CO_2 emission is only half of that from petroleum diesel. So it is also known as a green diesel, or renewable diesel. Biodiesel can be produced using such technologies as NExBTL renewable diesel producing technology (Mikkonen, 2008), the Ecofining green diesel producing technology (Egeberg et al., 2010), Haldor Topsoe renewable diesel producing technology (Egeberg et al., 2010), and EERC renewable diesel producing technology (Wocken et al., 2010), etc . Biodiesel is significantly superior to the No. 2 diesel widely used in the developed countries.

5.1.2.1 Microbial decomposition of cellulose to produce biodiesel

Microbes can be used to break down cellulose for producing biodiesel. Arizona State University, partnered with British Petroleum and Science Foundation Arizona, used a special optimized photosynthetic bacterium to produce biodiesel. The culture of this bacterium only needs solar energy and environmental control equipments.

5.1.2.2 Use waste plastics to produce biodiesel

For example, students in the Department of Mechanical Engineering of the University of Madras, India, have successfully converted waste plastic into vehicle fuel. Waste plastic was placed in the vacuum with a catalyst and was heated, and waste plastic gradually melted into its original form - oil. Then after distillation and purification, waste plastic was eventually converted into gasoline, diesel and kerosene, and the entire process did not produce carbon dioxide. According to this method, 2.5 kg of waste plastic can be used to produce 1 liter of gasoline, 0.5 liter diesel and 0.5 liter of kerosene, and production cost is about $ 1.5.

5.2 Third-generation biofuels

The cost for production of the second-generation biofuels is higher. Therefore, the development of the third-generation biofuels has been on the agenda. The third-generation technologies use, mainly algae, as raw material to produce bioethanol, biobutanol, biodiesel, and hydrogen (Sayadi et al., 2011). Algae not only can be cultivated in waste water or marine aquaculture, but also will not pollute the environment.

5.2.1 Use algae to produce biofuel

Algae survive in almost all of natural waters. With the help of solar energy and carbon dioxide, they can survive in sea waters and waste water. They grow rapidly and can be harvested per several days. About 1 km^2 of algae can store 50 thousand tons of carbon dioxide each year without input of fertilizers and pesticides. In this technology, as a nutrient of algae, carbon dioxide can be directly transported to the algae pool and absorbed by algae. Industrial technologies for using algae to produce biofuel are under trial. Large-scale commercial production will still take some years.

5.2.2 Use discarded fruits to produce dimethylfuran

Dimethylfuran is a new type of biofuel. As a biofuel, it was initially manufactured by American scientists using discarded fruit. Many fruits are hard to be stored for a longer period. Rotten and degenerated fruits are always discarded as litter. The scientists in the University of Wisconsin-Madison found that monosaccharides in fruits can be transformed into a more advantageous fuel, dimethylfuran, than ethanol fuel. Compared to ethanol, the combustion energy generated by dimethylfuran is 40% higher than ethanol, similar to gasoline. The boiling point of dimethylfuran is nearly 20°C higher than ethanol and thus is a more stable fuel at room temperature. Its manufacturing process is similar to the methods used in the petroleum and chemical industry and therefore easy to be produced. It can also be tested for blending with gasoline.

6 Future Prospects

In our view, in the future the raw materials for biofuel production will be focused on various by-products, wastes, and organisms that have not direct economic benefit for human. Production technologies should be improved or invented to reduce carbon emission and environmental pollution during biofuel production and to reduce production cost. Biofuel industry is developing rapidly. We expect that more biofuels and technologies will emerge in the future.

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